# DETERMINATION OF MONTHLY CROP COEFFICIENTS FOR THE BLANEY-CRIDDLE CONSUMPTIVE USE FORMULA

by

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## INTRODUCTION

The irrigated acreage in Kansas has greatly increased in the last fifteen years. According to "Farm Acre Report", an agricultural census, there were 96,248 acres under irrigation in 1945. By 1949, a survey by Walter Selby, Extension Engineer, of county agricultural agents' reports and county clerks' records showed 248,067 acres were irrigated. The relatively wet period of the early 1950's discouraged new irrigation development. The county agricultural agents' annual reports indicated 420,000 acres were irrigated in 1954. A tremendous increase in new irrigated acreage occured during the following four years. By the end of 1958, the county agricultural agents' annual reports showed 899,755 acres were under irrigation in Kansas.

It is difficult to predict the amount of new irrigation development for the future in Kansas. There are many acres of land suited for irrigation. Costs of development and the available water supply will limit additional irrigated acreages. However, it appears probable that a total of 1,500,000 acres could be under irrigation in Kansas within 15 to 20 years if the water resources of the state are properly developed.

Irrigation farmers are in direct competition with domestic and industrial water users for the available water supply. Growing cities and industries have ever increasing water needs. Also, irrigation will continue to increase as farmers look for ways to stabilize farm income and provide food for an ever growing population. Water, out of necessity, must be efficiently used to be of most benefit to its users.

For maximum crop production, a plentiful supply of soil moisture must be maintained in the crop root zone throughout its growing season. To have

an irrigation project with sufficient capacity to meet crop needs, water requirements of crops must be known.

## PURPOSE

The purpose of this study was to determine the accuracy of the Blaney-Criddle formula for estimating consumptive use of corn in north central Kansas. Monthly consumptive use crop coefficients for use in the formula were calculated for June, July, August and September for the years 1954-1957.

Calculated average monthly crop coefficients were used to estimate consumptive use for 1954, 1955, 1956 and 1957. Estimated consumptive use was compared with measured consumptive use for each of the four years to determine if the Blaney-Criddle formula is sufficiently accurate for scheduling irrigations.

## REVIEW OF LITERATURE

Various methods have been used to estimate irrigation requirements for new and existing projects. For the first irrigation projects started in the United States, no attempt was made to estimate water requirements. Water was simply diverted to lands adjacent to the water supply. If the canals were too small, they were enlarged to meet the needs. As new projects were constructed, canal sizes and capacities were estimated from experience gained on previous irrigation systems. However, most of the less complicated and less expensive projects have been developed. New sources of irrigation water supplies have become limited while the potential area of irrigable land is large. Only that land which can be served adequately and economically can now be brought under irrigation. These

factors have presented a need for a procedure to estimate irrigation requirements in the planning state of an irrigation project.

Irrigation requirement is defined by Blaney and Criddle (5) as the quantity of water, exclusive of precipitation that is required for crop production. It includes surface evaporation and other economically unavoidable wastes. The net amount of irrigation water necessary to satisfy crop needs is found by subtracting effective precipitation from consumptive use requirements.

Consumptive use is defined by Blaney and Criddle (5) as:

> The sum of the volumes of water used by the vegetative growth of a given area in transpiration and building of plant tissues and that evaporated from adjacent soil, snow, or intercepted precipitation on the area in any specified time, divided by the area.

Consumptive use and evapotranspiration are considered synonymous and will be used interchangeably in this thesis.

For many years climatological data have been recorded by the United States Weather Bureau. Attempts have been made by many scientists to correlate climatic data with consumptive use. If long time records of all climatic factors affecting consumptive use were available, an empirical formula could probably be derived. This formula would take into account the effects of each factor and could be applied with sufficient accuracy for average conditions in any area. Unfortunately, only part of the climatic factors have been previously measured. In most areas measurements have been limited to temperature and precipitation.

The Blaney-Criddle consumptive use formula was developed from results of experimental studies throughout the western United States. It is an empirical formula showing the relationship between temperature, length of growing season, monthly per cent of annual daytime hours and consumptive

use of water. The equation was developed to estimate water requirements for irrigated lands where practically no data, except climatological, were available. The procedure is to measure consumptive use, evaluate the consumptive use factor, and calculate the consumptive use crop coefficient. The coefficients thus obtained are used to transpose the consumptive use data for an area to other areas where only climatological data are available.

The Blaney-Criddle consumptive use formula, as used in this study, is $u = k\ f$, where

$u$ = Monthly consumptive use in inches

$k$ = Monthly consumptive use crop coefficient

$f = \frac{t \times p}{100}$ = Monthly consumptive use factor

$t$ = Mean monthly temperature in $^{\circ}$ F.

$p$ = Monthly per cent of daytime hours of the year.

The formula is also written and widely used as $u = K\ f$, where

$K$ = Seasonal consumptive use crop coefficient.

In this form, the same crop coefficient is used for each month of the growing season, regardless of stage of plant growth.

The basic form of the Blaney-Criddle formula is $U = K\ F$, where

$U$ = Seasonal consumptive use in inches

$F$ = Sum of the monthly consumptive factors, $f$, for the season.

Another often used formula for estimating evapotranspiration was derived by Thornthwaite (18). Study of available data has resulted in a formula that permits computation of consumptive use at any location if its latitude is known and temperature data are available. The Thornthwaite formula is:

$$P\,E\,T = 1.6 \left(\frac{10\ T}{I}\right)^{a}$$

where

$P\,E\,T$ = Potential evapotranspiration in cm

$T$ = Mean temperature in $^{o}C$ for the period under consideration

$I$ = Heat index which is a constant for a given location and is the sum of the monthly index values $i$

$$a = 6.75 \times 10^{-7}\ I^{3} - 7.71 \times 10^{-5}\ I^{2} + 1.79 \times 10^{-2}\ I + 0.49$$

$i = \left(\frac{t}{5}\right)^{1.514}$ where $t$ is mean monthly temperature

Thornthwaite found the rate of evapotranspiration depends on four factors: climate, soil moisture supply, plant cover and land management. Of these four factors, climate and soil moisture supply are the most important. Thornthwaite indicates plant cover is a minor factor in evapotranspiration and that transpiration from a completely covered area depends more on the amount of solar energy received than on the kind of plants growing.

A formula for estimating consumptive use from climatological data has been derived by Penman (13). Penman's formula is:

$$E = \frac{\Delta H + \gamma E_a}{\Delta + \gamma}$$

where

$E$ = Evaporation from open water surface

$\Delta$ = Rate of change of saturated vapor pressure with temperature

$$H = 0.0157\ R\ (0.18+0.55\ \frac{n}{N}) - \frac{1955.52T^{4}\ (0.56-0.092\sqrt{h\ e_a})(0.1+0.9\ \frac{n}{N})}{10^{12}}$$

$$E_a = 0.35\ (1 - h)\ (1 + 0.54\ u_2)\ e_a$$

$\gamma$ = 0.486 (psychrometer constant)

$R$ = Solar radiation received at the top of the atmosphere by a horizontal surface

$e_a$ = Saturation pressure of water vapor at temperature T

$T$ = Temperature in $^oK$

$n$ = Actual duration of sunshine

$N$ = Maximum possible sunshine duration

$h$ = Relative humidity

$u_2$ = Wind speed at a height of 2 meters.

The basic assumptions for Penman's formula are there must be an energy supply to provide heat of vaporization and there must be some transport mechanism for removing the vapor. Combining these concepts, he has developed a formula that depends only on measureable weather elements. The weather data needed are duration of bright sunshine, air temperature, air humidity and wind speed.

Penman's work was done in England using a short, green cover crop completely shading the ground and never short of water. A considerable part of Thornthwaite's work was done in the eastern part of the United States. Blaney found that measurements of evapotranspiration in arid and semi-arid areas of the western United States indicate that plant and soil types are major factors in evapotranspiration rather than minor factors as found by both Penman and Thornthwaite.

The Blaney-Criddle consumptive use formula was selected for this study. It was developed in the western part of the United States where climatic conditions are similar to those found in the major irrigated areas of Kansas. Also, the climatological data needed are available for most of the state.

Information available at the beginning of this study on consumptive

of water by crops in Kansas was very limited. Hanson and Meyer (8) in 1953 published estimates for Kansas based on the Blaney-Criddle consumptive use formula. A seasonal crop coefficient K of 0.75 was used for these estimates.

Blaney and Criddle (5) reported consumptive use crop coefficients for corn at several locations. In 1947 a K value of 0.96 was reported at Bonners Ferry, Idaho, for the growing season of May 8 to September 27. Also an average K value of 0.96 was observed at Logan, Utah, for the period June 1 to September 30, during the years 1902 to 1929. At Vernal, Utah, a K value of 0.95 was recorded in 1948 for the growing season of June 10 to September 20. In 1918 a K value of 0.70 was reported for Mercedes, Texas, for the period March 15 to July 15. A relatively low K value of 0.45 was observed at Davis, California, for the growing season of June 1 to September 30. According to Blaney and Criddle (5) the consumptive use coefficient has an average value of 0.75 to 0.85 for corn with a four-month growing season in the western states. The lower value of K applies to the coastal areas with the higher value for areas with an arid climate.

Several methods have been tried to measure directly consumptive use. One method used was to weigh periodically leaves and branches removed from the growing plant. The rate of water loss was a measure of the rate of water use. Unrealistic values of rate of water use were obtained.

The vapor transfer method is the only method thus far developed that measures evapotranspiration directly without distrubing the plant. By this method, plants are grown in sealed containers and the amount of moisture in the air is measured periodically. The vapor transfer method is seldom used for determining evapotranspiration as it requires physical measurements more precise than those usually made.

The difficulty of measuring evapotranspiration direct has led to

indirect measurements. Various indirect methods have been used to determine the consumptive use of plants. These methods include (a) using lysimeter tanks, (b) measuring loss of water from the soil profile, and (c) assuming irrigation water applied and rainfall received is all used as evapotranspiration.

Most corn irrigated in Kansas is watered in furrows. Soil samples to determine moisture content of the soil can be taken either in the row, on the shoulder of the furrow, or in the bottom of the furrow. Allmaras and Gardner (1) found variations due to the sampling on the ridge, shoulder or furrow and that due to gravity flow of water down the row was negligible. Soil samples for this study were taken on the shoulder of the furrow.

The need for a practical way to determine when to irrigate has long been recognized. As a result there are now available tensiometers, electrical and thermal conductivity units, and other instruments to measure soil moisture. These instruments have been useful in research but none of the units are satisfactory for field use. This is due mainly to the small volume of soil sampled and the resulting variation between replicate installations.

Many researchers are working on methods to estimate soil moisture conditions and time of irrigation from climatological data. They are making use of formulas developed by Penman, Thornthwaite, Blaney and Criddle, and variations of these. Harrold (10) has found that the application of some empirical methods results in over-all seasonal totals close to the measured values but some of the monthly values deviate too much for some uses.

Pruitt and Jensen (15) have compared results of determining when to

irrigate by use of Thornthwaite formula, Blaney-Criddle formula, and evaporation tank data. They state:

> During periods of good crop cover, tank-evaporation rates gave a much closer estimate of actual consumptive rates than either the Blaney-Criddle or Thornthwaite procedure. Although high correlation coefficients resulted from statistically comparing each of the three methods with consumptive use, it was found that for the Blaney-Criddle method the value for the crop coefficient should vary throughout the season.

## METHOD AND PROCEDURE

### Scope of Study

The study reported in this thesis is limited to determining the consumptive use crop coefficients for the Blaney-Criddle consumptive use formula. Measurements were made for corn only. Corn is the number one crop grown under irrigation in north central Kansas and is therefore the logical crop to study.

Consumptive use crop coefficients were determined for only those months during the growing season. Planting date for corn varied from May 19 to June 11 during the four years for which data were available. To obtain data for the same period each year, the following intervals were used for each month:

1. June - June 15 to June 30
2. July - July 1 to July 31
3. August - August 1 to August 31
4. September - September 1 to September 30
5. October - October 1 to October 31.

### Location of Consumptive Use Measurements

A corn irrigation treatment test was initiated at the Concordia Irrigation Experiment Field in 1954 and continued through 1957. The

purpose of this test was to study the influence of time and amount of water applied on the production of corn. Soil moisture was measured at the beginning and end of the growing season and also before and after each irrigation. This soil sampling data was used to measure consumptive use.

The Concordia Irrigation Experiment Field was located nine miles northwest of Concordia, Kansas. The area is alluvial soil situated on the second terrace of the Republican River Valley. The surface soil is silt underlain with silty clay loam and then by clay. After the initial application of water infiltration was slow averaging about 0.15 inches per hour.

## Cultural Practices

The corn irrigation test was laid out in a randomized block type experiment with four replications. Each plot was 20 feet wide and approximately 200 feet long. Six corn rows were planted in each plot with the two center rows as test rows.

The corn irrigation test was set up in a rotation following corn. A total of 125 pounds of elemental nitrogen per acre was applied each year. Adjacent fertility studies indicated sufficient soil nutrients were available for maximum corn yields except possibly for 1957 when the addition of phosphorus may have increased yields. However, the corn irrigation treatment yields were as high or higher in 1957 as in 1954 and 1956. This would indicate that fertility level was approximately the same throughout the test and water use was not affected by variation in yields from year to year.

Kansas hybrid K 1830 was planted during the period May 19 to June 11 in 40-inch rows. Sufficient kernels were planted to obtain the desired

plant population without subsequent thinning. Adjacent spacing studies indicated a plant population of 14,000 to 17,000 plants per acre would give maximum yields. Table 1 shows plant population for each treatment and each year of the test. Only in 1954 was the plant population appreciably outside this optimum range. In 1954 plant population was 20,000 plants per acre. It is believed this high plant population was not sufficient to materially alter water use.

The yield of corn for grain was determined by hand picking the center two rows of each plot and weighing the grain. Corn yields corrected to 15.5 per cent moisture are shown in Table 1.

## Irrigation Practices

Various irrigation treatments were used during the four years of the test. Therefore no treatment was the same for each year studied. The treatments were set up to determine the proper criteria for irrigating corn in north central Kansas. For the purposes of this thesis the treatment merely identifies the soil sampling data to be used in consumptive use computations.

The corn plots were irrigated using siphon tubes to divert water from an open ditch into level furrows. The furrows were blocked at the ends to prevent runoff from the plots. Water was measured with an orifice plate as it discharged from the irrigation pump. A record of water pumped and dates of irrigation is shown in Table 1.

Water losses, due to evaporation and seepage occurred in conveying the water to the individual plots. These losses were not measured as consumptive use of the corn was measured by soil sampling. However, care was taken in setting the siphon tubes so each row received approximately

Table 1. Irrigation and corn yield data.

| Treatment | Dates of Irrigation | Water Applied Inches | Population Plants/A | Yield * B/A |
|---|---|---|---|---|
| | 1954 | | | |
| 1 | 7-29 | 7.5 | 19,925 | 90.3 |
| 2 | 7-22 | 4.6 | 19,765 | 83.0 |
| 3 | 7-22; 8-21 | 9.6 | 20,113 | 88.1 |
| 4 | 7-15; 7-31; 9-4 | 14.9 | 19,844 | 87.2 |
| 5 | 7-15; 7-25; 8-6; 9-6 | 21.0 | 19,525 | 80.4 |
| | 1955 | | | |
| 1 | 7-29 | 8.2 | 14,796 | 83.3 |
| 2 | 7-21; 8-2; 8-25 | 11.6 | 14,297 | 89.1 |
| 3 | 7-26; 8-16; 8-30 | 18.5 | 14,997 | 101.6 |
| 4 | 7-21; 8-2; 8-23 | 17.6 | 15,373 | 99.5 |
| 5 | 7-13; 7-26; 8-5; 8-19; 8-31 | 28.8 | 15,050 | 105.7 |
| 6 | 7-13; 8-2; 8-23 | 17.0 | 15,190 | 100.6 |
| | 1956 | | | |
| 1 | 5-26; 7-30 | 14.7 | 16,905 | 74.0 |
| 2 | 5-26; 7-30; 8-29; 9-22 | 20.0 | 17,150 | 74.6 |
| 3 | 5-26; 7-30; 8-29; 9-22 | 24.5 | 17,255 | 83.7 |
| 4 | 5-26; 7-30; 8-29; 9-22 | 24.5 | 17,325 | 86.7 |
| 5 | 5-26; 7-30; 8-9; 8-29; 9-22 | 29.7 | 17,045 | 88.4 |
| 6 | 5-26; 7-30; 8-29; 9-22 | 24.5 | 17,430 | 80.3 |
| | 1957 | | | |
| 1 | 7-25 | 5.6 | 17,000 | 87.6 |
| 2 | 7-25; 8-19 | 9.4 | 17,200 | 87.6 |
| 3 | 7-25; 8-19 | 9.4 | 18,000 | 94.3 |
| 4 | 7-25; 8-14; 9-4 | 12.6 | 17,000 | 90.3 |

* Corn yields corrected to 15.5 per cent moisture.

the same stream flow.

In 1956 rainfall in January through May was approximately six inches below average. This resulted in a very low soil moisture level before planting so a pre-season irrigation was made late in May. The soil reservoir was filled during this irrigation, thereby making water readily available to the crop as needed until water was again applied in late July. This was the only year that a pre-season irrigation was made.

## Soil Moisture Determinations

Soil moisture samples were taken at 9-inch increments to a depth of 54 inches with a King type soil sampling tube. A ¾-inch diameter sample of soil was taken for moisture determinations. Sampling was done six to ten inches from the corn row and on the shoulder of the furrow.

Soil samples were placed in air tight moisture cans and weighed later. All weights were read to the nearest 0.1 gram. To eliminate as many weight readings as possible the average weight of the moisture cans was used as tare weight. The scales were adjusted to correct for the tare weight of the cans. Weight of soil samples were read direct from the scales.

The wet soil samples were weighed, the weight recorded, and the samples were then placed in a forced-air oven at approximately 105° C for 24 hours or until the soil was dry. The samples were weighed after drying and the weight of dry soil recorded. Moisture per cent by weight, $P_w$, was easily calculated as follows:

$$P_w = \frac{\text{weight wet soil}}{\text{weight dry soil}} - 1.0 \quad x\ 100$$

Moisture per cent by volume, $P_v$, is equal to $P_w$ x $D_b$, where $D_b$ is the bulk density of the soil. The bulk density was determined for the Irrigation Field when it was established and these values were used for this study.

The soil profile was sampled in nine-inch intervals. The amount of water in each interval is equal to $P_v$ times nine inches. The total water in the 54-inch profile was the sum of the six nine-inch increments.

Consumptive use was measured by the change in soil moisture in the soil profile between samplings. Soil moisture for each treatment was determined by averaging the moisture content of the four replications.

Consumptive use during each irrigation period was estimated. All the rainfall that fell was assumed to be effective and was added to the use during the period it fell. This may not be entirely true. The area was in level furrows so none of the rainfall was lost as runoff. Small rains would be intercepted by the plant foliage and later lost by evaporation. However, most rain storms are accompanied by cloudiness and high humidity which tend to reduce transpiration and evaporation from plant foliage.

Tables in the appendix show the consumptive use of water during each season for the various irrigation treatments.

## Weather Data

Mean monthly temperatures and monthly per cent of daytime hours of the year are needed to evaluate the consumptive use factor. Table 2 gives mean monthly temperatures as recorded at the United States Weather Bureau Station at Concordia, Kansas.

Table 2. Mean monthly temperatures at Concordia, Kansas.

| | 1954 | 1955 | 1956 | 1957 | Mean* |
|---|---|---|---|---|---|
| January | 26.4 | 30.0 | 24.9 | 21.3 | 27.3 |
| February | 44.7 | 25.4 | 29.6 | 36.3 | 31.2 |
| March | 38.6 | 40.0 | 41.6 | 41.0 | 41.2 |
| April | 58.4 | 60.2 | 49.8 | 50.8 | 53.7 |
| May | 59.7 | 67.2 | 68.0 | 61.4 | 63.1 |
| June | 77.2 | 70.4 | 78.3 | 71.9 | 73.5 |
| July | 85.4 | 84.5 | 80.1 | 82.9 | 79.2 |
| August | 79.7 | 81.7 | 80.9 | 80.3 | 77.6 |
| September | 74.6 | 71.1 | 72.7 | 65.6 | 69.1 |
| October | 57.5 | 57.8 | 62.8 | 54.5 | 56.9 |
| November | 47.4 | 35.4 | 41.5 | 39.2 | 42.0 |
| December | 35.5 | 27.3 | 36.4 | 38.6 | 31.6 |

* Mean is taken for the period since 1905.

Daytime hour percentages for each month are given in Table 3. These values were computed from sunshine tables published by the United

States Weather Bureau.

Records are also maintained at the Concordia Weather Station of per cent possible total sunshine hours. This information is given in Table 4 for the period 1954 through 1957.

Table 3. Daytime hour percentages for each month.

| Month | Latitudes in degrees north of equator | | |
|---|---|---|---|
| | 38 | 40 | 39.6* |
| January | 6.87 | 6.76 | 6.78 |
| February | 6.79 | 6.73 | 6.74 |
| March | 8.34 | 8.33 | 8.33 |
| April | 8.90 | 8.95 | 8.94 |
| May | 9.92 | 10.02 | 10.00 |
| June | 9.95 | 10.08 | 10.05 |
| July | 10.10 | 10.22 | 10.20 |
| August | 9.47 | 9.54 | 9.53 |
| September | 8.38 | 8.38 | 8.38 |
| October | 7.80 | 7.75 | 7.76 |
| November | 6.82 | 6.72 | 6.74 |
| December | 6.66 | 6.52 | 6.55 |

* Latitude for Concordia, Kansas

Table 4. Per cent of possible sunshine hours at Concordia, Kansas.

| | 1954 | 1955 | 1956 | 1957 |
|---|---|---|---|---|
| January | 63 | 64 | 61 | 64 |
| February | 81 | 52 | 59 | 62 |
| March | 65 | 68 | 77 | 46 |
| April | 62 | 71 | 72 | 52 |
| May | 51 | 50 | 55 | 60 |
| June | 79 | 41 | 87 | 71 |
| July | 79 | 80 | 85 | 83 |
| August | 58 | 95 | 75 | 84 |
| September | 83 | 74 | 91 | 77 |
| October | 54 | 77 | 84 | 55 |
| November | 70 | 71 | 82 | 53 |
| December | 66 | 67 | 74 | 65 |

Precipitation data as well as temperature and sunshine data are needed to evaluate irrigation requirements. Table 5 is a summary of

annual precipitation at the Concordia Weather Station.

Table 5. Summary of annual precipitation at Concordia, Kansas.

| | 1954 | 1955 | 1956 | 1957 | Mean* |
|---|---|---|---|---|---|
| January | .08 | 1.24 | .81 | .51 | .59 |
| February | .77 | 1.02 | .26 | .37 | .87 |
| March | .09 | .31 | .06 | 1.86 | 1.27 |
| April | 1.42 | .88 | 1.06 | 5.22 | 2.29 |
| May | 5.79 | 1.88 | .99 | 5.46 | 3.98 |
| June | 2.36 | 3.42 | 4.03 | 4.37 | 4.30 |
| July | .93 | 1.86 | 1.58 | 1.11 | 3.27 |
| August | 6.69 | .53 | 1.84 | 1.33 | 3.04 |
| September | 1.79 | 3.73 | .08 | 2.07 | 2.52 |
| October | 1.97 | .76 | 1.48 | 1.00 | 1.81 |
| November | .01 | .13 | .54 | 1.47 | 1.03 |
| December | .49 | .43 | .10 | .58 | .66 |
| TOTAL | 22.39 | 16.19 | 12.83 | 25.35 | 25.60 |

* Mean is taken for the period since 1905.

## RESULTS OF STUDY

### Consumptive Use Measurements

Monthly consumptive use crop coefficients were desired for conditions of optimum plant growth and maximum corn yields. Consumptive use under optimum conditions was needed to calculate the crop coefficients. Consumptive use measurements were made for the years 1954 through 1957 on irrigation treatments of various soil moisture levels. All the measurements could have been used to estimate the value of the crop coefficients. Obviously all the irrigation treatments did not give optimum soil moisture conditions. Under some treatments insufficient water was applied for maximum crop growth resulting in reduced plant transpiration. Other treatments receiving too much water would have a resulting excess evaporation from the soil surface.

For purposes of statistical analysis, two crop coefficients were

needed for each month considered of each year. The two treatments resulting in the two highest yields of each year were selected for use in this study. These treatments were one and three in 1954, three and five in 1955, four and five in 1956, and three and four in 1957.

## Calculation of Consumptive Use Crop Coefficients

The consumptive use measurements were plotted as shown in Figs. 1, 2, 3, and 4. Time of season was plotted along the absicca and accumulated consumptive use along the ordinate. An eye curve was drawn through the plotted points.

The soil moisture sampling period was not the same for each year. Neither were samples taken on the first of each month. Monthly consumptive use was read off the consumptive use curves, Figs. 1, 2, 3 and 4. Monthly consumptive use is given in Table 6 along with mean monthly temperature, monthly per cent of daytime hours of the year, and monthly consumptive use factor.

The monthly consumptive use crop coefficient is equal to monthly consumptive use divided by consumptive use factor. The calculated values of k are given in Table 6.

The seasonal consumptive use crop coefficients were calculated. The K values were 0.71 in 1954, 0.95 in 1955, 1.05 in 1956, and 0.96 in 1957. An average K value of 0.92 was found for the period June 15 to September 30 during the four years of this study.

## Analysis of Crop Coefficients

Monthly consumptive use crop coefficients were calculated for June, July, August, and September for each of the years 1954 through 1957. As

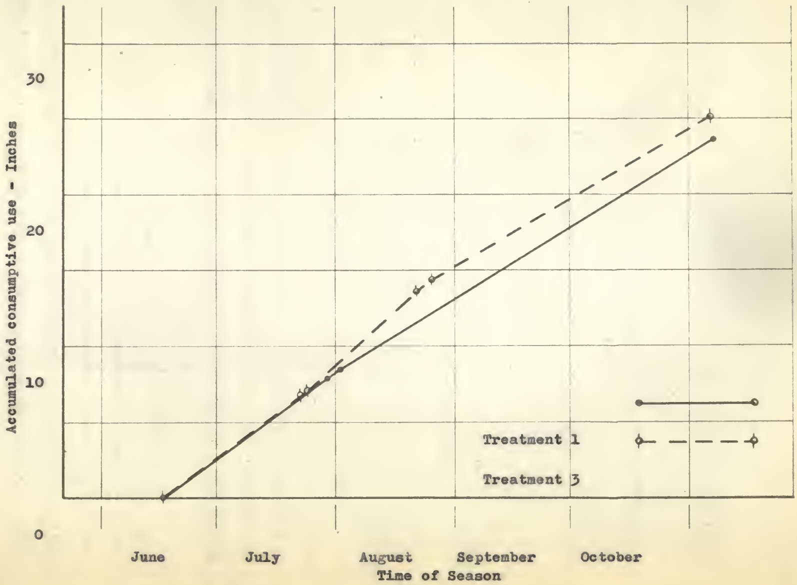


Fig. 1. Consumptive use of water by corn - 1954.

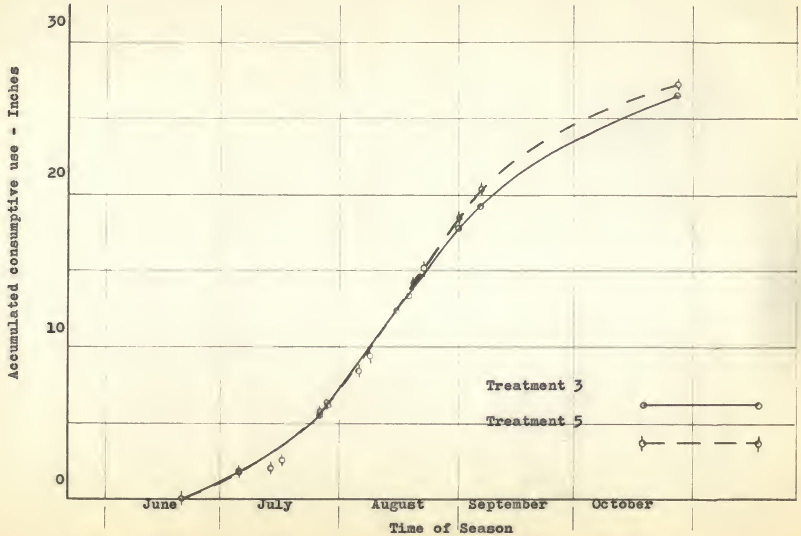


Fig. 2. Consumptive use of water by corn - 1955.

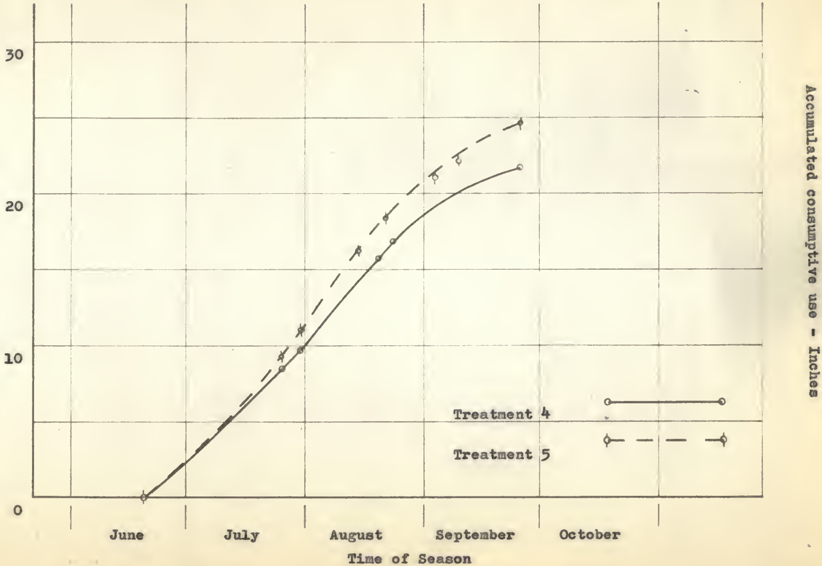


Fig. 3. Consumptive use of water by corn - 1956.

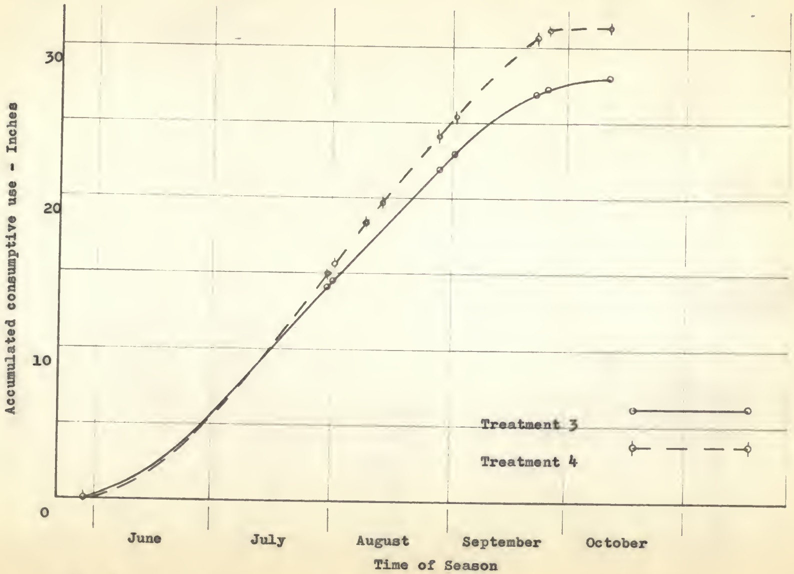


Fig. 4. Consumptive use of water by corn - 1957.

Table 6. Factors for solution of Blaney-Criddle formula, u = kf.

| Treatment | Date | Accumulated Use Inches | u Inches | t $^oF$ | p % | f | k |
|---|---|---|---|---|---|---|---|
| 1 | 6-15-54 | - 0.15 | - | - | - | - | - |
| | 6-30-54 | 2.65 | 2.80 | 77.2 | 10.05 | 7.76 | .72 |
| | 7-31-54 | 8.45 | 5.80 | 85.4 | 10.20 | 8.71 | .67 |
| | 8-31-54 | 13.20 | 4.75 | 79.7 | 9.53 | 7.57 | .63 |
| | 9-30-54 | 17.80 | 4.60 | 74.6 | 8.38 | 6.25 | .74 |
| | 10-31-54 | 22.60 | 4.80 | 57.5 | 7.76 | 4.46 | 1.08 |
| 3 | 6-15-54 | - 0.15 | - | - | - | - | - |
| | 6-30-54 | 2.65 | 2.80 | 77.2 | 10.05 | 7.76 | .72 |
| | 7-31-54 | 8.90 | 6.25 | 85.4 | 10.20 | 8.71 | .72 |
| | 8-31-54 | 15.20 | 6.30 | 79.7 | 9.53 | 7.57 | .83 |
| | 9-30-54 | 19.60 | 4.40 | 74.6 | 8.38 | 6.25 | .70 |
| | 10-31-54 | 24.25 | 4.65 | 57.5 | 7.76 | 4.46 | 1.04 |
| 3 | 6-15-55 | - 0.60 | - | - | - | - | - |
| | 6-30-55 | 1.20 | 1.80 | 70.4 | 10.05 | 7.08 | .51 |
| | 7-31-55 | 7.10 | 5.90 | 84.5 | 10.20 | 8.62 | .68 |
| | 8-31-55 | 17.85 | 10.75 | 81.7 | 9.53 | 7.76 | 1.39 |
| | 9-30-55 | 23.45 | 5.60 | 71.1 | 8.38 | 5.96 | .94 |
| | 10-31-55 | 27.10 | 3.65 | 57.8 | 7.76 | 4.49 | .81 |
| 5 | 6-15-55 | - 0.60 | - | - | - | - | - |
| | 6-30-55 | 1.05 | 1.65 | 70.4 | 10.05 | 7.08 | .47 |
| | 7-31-55 | 6.60 | 5.55 | 84.5 | 10.20 | 8.62 | .64 |
| | 8-31-55 | 18.65 | 12.05 | 81.7 | 9.53 | 7.76 | 1.55 |
| | 9-30-55 | 24.30 | 5.65 | 71.1 | 8.38 | 5.96 | .95 |
| | 10-31-55 | 27.65 | 3.35 | 57.8 | 7.76 | 4.49 | .75 |
| 4 | 5-31-56 | 0.30 | - | - | - | - | - |
| | 6-15-56 | 2.15 | 1.85 | 78.3 | 10.05 | 7.87 | .47 |
| | 6-30-56 | 5.65 | 3.50 | 78.3 | 10.05 | 7.87 | .89 |
| | 7-31-56 | 14.30 | 8.65 | 80.1 | 10.20 | 8.17 | 1.06 |
| | 8-31-56 | 22.80 | 8.50 | 80.9 | 9.53 | 7.69 | 1.11 |
| | 9-30-56 | 27.65 | 4.85 | 72.7 | 8.38 | 6.09 | .80 |
| 5 | 5-31-56 | 0.30 | - | - | - | - | - |
| | 6-15-56 | 2.30 | 2.00 | 78.3 | 10.05 | 7.87 | .51 |
| | 6-30-56 | 5.65 | 3.35 | 78.3 | 10.05 | 7.87 | .85 |
| | 7-31-56 | 15.55 | 9.90 | 80.1 | 10.20 | 8.17 | 1.21 |
| | 8-31-56 | 25.35 | 9.80 | 80.9 | 9.53 | 7.69 | 1.27 |
| | 9-30-56 | 31.25 | 5.90 | 72.7 | 8.38 | 6.09 | .97 |
| 3 | 6-15-57 | - 0.70 | - | - | - | - | - |
| | 6-30-57 | 2.25 | 2.95 | 71.9 | 10.05 | 7.23 | .82 |
| | 7-31-57 | 10.05 | 7.80 | 82.9 | 10.20 | 8.46 | .92 |
| | 8-31-57 | 18.50 | 8.45 | 80.3 | 9.53 | 7.63 | 1.11 |
| | 9-30-57 | 22.05 | 3.55 | 65.6 | 8.38 | 5.50 | .65 |
| 4 | 6-15-57 | - 0.70 | - | - | - | - | - |
| | 6-30-57 | 2.30 | 3.00 | 71.9 | 10.05 | 7.23 | .83 |
| | 7-31-57 | 11.20 | 8.90 | 82.9 | 10.20 | 8.46 | 1.05 |
| | 8-31-57 | 19.50 | 8.30 | 80.3 | 9.53 | 7.63 | 1.09 |
| | 9-30-57 | 24.90 | 5.40 | 65.6 | 8.38 | 5.50 | .98 |

stated before, the coefficient for June is for the period June 15 to June 30. Coefficients were also calculated for October in 1954 and 1955 and the first half of June in 1956.

A statistical analysis was made to determine if the monthly crop coefficients were the same each year or if their value varied from year to year. For this analysis, the months June, July, August and September were considered as it was desirable to have data for the same months each year. An analysis of variance test was made with two treatment effects. These treatment effects were months and years. Table 7 shows the computations for the statistical analysis.

Table 7. Statistical analysis of monthly crop coefficients.

| Months | Years | | | | Total for Months |
|---|---|---|---|---|---|
| | 1954 | 1955 | 1956 | 1957 | |
| June* | .72 | .51 | .89 | .82 | |
| | .72 | .47 | .85 | .83 | |
| Sum | 1.44 | .98 | 1.74 | 1.65 | 5.81 |
| Mean | .72 | .49 | .87 | .83 | |
| July | .67 | .68 | 1.06 | .92 | |
| | .72 | .64 | 1.21 | 1.05 | |
| Sum | 1.39 | 1.32 | 2.27 | 1.97 | 6.95 |
| Mean | .70 | .66 | 1.14 | .99 | |
| August | .63 | 1.39 | 1.11 | 1.11 | |
| | .83 | 1.55 | 1.27 | 1.09 | |
| Sum | 1.46 | 2.94 | 2.38 | 2.20 | 8.98 |
| Mean | .73 | 1.47 | 1.19 | 1.10 | |
| September | .74 | .94 | .80 | .65 | |
| | .70 | .95 | .97 | .98 | |
| Sum | 1.44 | 1.89 | 1.77 | 1.63 | 6.73 |
| Mean | .72 | .95 | .89 | .82 | |
| TOTAL FOR YEARS | 5.73 | 7.13 | 8.16 | 7.45 | 28.47 |

C = 25.3294
Total sum of squares = 27.2427 - 25.3294 = 1.9133
Treatment sum of squares = 27.1038 - 25.3294 = 1.7744
Error sum of squares = 1.9133 - 1.7744 = .1389
Years sum of squares = 25.7197 - 25.3294 = .3903
Months sum of squares = 25.9990 - 25.3294 = .6696
Years x months sum of squares = 1.7744 - .3903 - .6696 = .7145

Table 7 (concl.)

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square | F |
|---|---|---|---|---|
| Treatment Effects | | | | |
| Years | 3 | 0.3903 | | |
| Months | 3 | 0.6696 | | |
| Years x Months | 9 | 0.7145 | 0.0794 | 9.13 |
| Error | 16 | 0.1389 | 0.0087 | |
| TOTAL | 31 | 1.9133 | | |

* For period June 15 to June 30.

Results of Crop Coefficient Analysis

An F test was made of years times months compared to the error term in the analysis of variance table. A highly significant F value of 9.13 was obtained indicating an interaction between years and months. This shows consumptive use is not related to mean temperature and sunshine hours in the same way each year as is assumed in the Blaney-Criddle formula.

Estimated consumptive use was compared to measured consumptive use. Average monthly consumptive use crop coefficients found in this study were used to estimate consumptive use for each year of the test. It was hoped these mean monthly coefficients could be used to accurately estimate water use and thereby be used to schedule irrigations. Table 8 gives the average monthly crop coefficients along with the measured and estimated consumptive use for the four years of the study.

A good irrigated soil is capable of storing from 2.0 to 2.2 inches of available soil moisture per foot of depth. Soil sampling has shown corn has a four-foot root zone at the Concordia Experiment Field. The soil profile can then store a maximum of 8 to 8.8 inches of available moisture. The difference between estimated and measured consumptive use varied from a maximum of 6.19 inches for treatment one in 1954 to 0.27 inches for

Table 8. Measured and estimated consumptive use - 1954 to 1957.

| Month | Average k | Estimated Use Inches | Estimated Accumulated Use Inches | Measured Accumulated Use Inches | Difference Inches | Measured Accumulated Use Inches | Difference Inches |
|---|---|---|---|---|---|---|---|
| 1954 | | | | | T-1 | | T-3 |
| June * | .73 | 2.83 | 2.83 | 2.80 | .03 | 2.80 | .03 |
| July | .87 | 7.58 | 10.41 | 8.60 | 1.81 | 9.05 | 1.36 |
| August | 1.12 | 8.48 | 18.89 | 13.35 | 5.64 | 15.35 | 3.54 |
| September | .84 | 5.25 | 24.14 | 17.95 | 6.19 | 19.75 | 4.39 |
| 1955 | | | | | T-3 | | T-5 |
| June * | .73 | 2.58 | 2.58 | 1.80 | .78 | 1.65 | .93 |
| July | .87 | 7.50 | 10.08 | 7.70 | 2.38 | 7.20 | 2.88 |
| August | 1.12 | 8.69 | 18.77 | 18.45 | .32 | 19.25 | .48 |
| September | .84 | 5.01 | 23.78 | 24.05 | .27 | 24.90 | 1.12 |
| 1956 | | | | | T-4 | | T-5 |
| June * | .73 | 2.87 | 2.87 | 3.50 | .63 | 3.35 | .48 |
| July | .87 | 7.11 | 9.98 | 12.15 | 2.17 | 13.25 | 3.27 |
| August | 1.12 | 8.61 | 18.59 | 20.65 | 2.06 | 23.05 | 4.46 |
| September | .84 | 5.12 | 23.71 | 25.50 | 1.79 | 28.95 | 5.24 |
| 1957 | | | | | T-3 | | T-4 |
| June * | .73 | 2.64 | 2.64 | 2.95 | .31 | 3.00 | .36 |
| July | .87 | 7.36 | 10.00 | 10.75 | .75 | 11.90 | 1.90 |
| August | 1.12 | 8.55 | 18.55 | 19.20 | .65 | 20.20 | 1.65 |
| September | .84 | 4.62 | 23.17 | 22.75 | .42 | 25.60 | 2.43 |

* For period June 15 to June 30.

treatment three in 1955. Estimates of soil moisture conditions in error as much as six inches would be of little value if the usable soil moisture reservoir held only 8.8 inches of available water. Therefore, it appears the Blaney-Criddle formula is not sufficiently accurate to schedule irrigations in north central Kansas.

The average monthly consumptive use crop coefficients found in this study were 0.73 for June 15 to June 30, 0.87 for July, 1.12 for August, and 0.84 for September. The largest coefficients were 22 per cent greater for June, 39 per cent greater for July, 38 per cent greater for August and 17 per cent greater for September than the respective monthly averages. These crop coefficients can be used in the Blaney-Criddle formula to estimate average monthly consumptive use for areas where only climatological data are available. This information is useful for estimating irrigation needs for an irrigation project or individual farm. To obtain peak monthly needs the coefficients should be increased approximately 20 per cent for June and September and 40 per cent for July and August.

## Calculation of Adjusted Consumptive Use Crop Coefficients

In the preceding statistical analysis it was noted consumptive use does not have the same relationship to mean temperature and sunshine hours each year. The consumptive use factor, f, was adjusted to see if a relationship could be found that did exist. Per cent of possible total sunshine hours per month, $p_a$, was used instead of daytime hour percentages for each month, p. The adjusted value, Pa, took into account the hours the sun actually shone rather than the potential sunshine hours. The consumptive use factor was adjusted and became $f_a$. This adjusted the

consumptive use crop coefficient which became $k_a$. The equation became

$$k_a = \frac{u}{f_a} .$$

Table 9 gives measured monthly consumptive use, adjusted consumptive use factors and adjusted consumptive use crop coefficients.

## Analysis of Adjusted Crop Coefficients

Adjusted monthly crop coefficients were calculated for June, July, August and September. A statistical analysis was made to see if mean monthly temperature and per cent of possible total sunshine hours accurately predict consumptive use of water by corn. Table 10 gives the computations for the analysis.

## Results of Adjusted Crop Coefficient Analysis

An F test was made comparing years times months with the error term in the analysis of variance table. A significant F value of 3.21 was obtained, indicating interaction between years and months. Apparently climatic factors other than mean temperature and sunshine hours greatly influence consumptive use of water by corn.

Measured consumptive use was compared with estimated consumptive use. Average adjusted monthly consumptive use crop coefficients and adjusted consumptive use factors were used for these estimates. Table 11 gives the average adjusted monthly crop coefficients along with measured and estimated consumptive use.

It should be noted the largest difference between measured consumptive use and estimated consumptive use was 4.04 inches. Estimates of available soil moisture which error in excess of 4.00 inches are not sufficiently accurate to schedule irrigations. It does not appear the

Table 9. Adjusted factors for solution of Blaney-Criddle formula $u=k_a\ f_a$.

| Treatment | Date | Accumulated Use Inches | u Inches | t °F | $p_a$ Per cent | $f_a$ | $k_a$ |
|---|---|---|---|---|---|---|---|
| 1 | 6-15-54 | - 0.15 | - | - | - | - | - |
| | 6-30-54 | 2.65 | 2.80 | 77.2 | 7.94 | 6.13 | .91 |
| | 7-31-54 | 8.45 | 5.80 | 85.4 | 8.06 | 6.88 | .84 |
| | 8-31-54 | 13.20 | 4.75 | 79.7 | 5.51 | 4.39 | 1.08 |
| | 9-30-54 | 17.80 | 4.60 | 74.6 | 6.96 | 5.19 | .89 |
| | 10-31-54 | 22.60 | 4.80 | 57.5 | 4.19 | 2.41 | 1.99 |
| 3 | 6-15-54 | - 0.15 | - | - | - | - | - |
| | 6-30-54 | 2.65 | 2.80 | 77.2 | 7.94 | 6.13 | .91 |
| | 7-31-54 | 8.90 | 6.25 | 85.4 | 8.06 | 6.88 | .91 |
| | 8-31-54 | 15.20 | 6.30 | 79.7 | 5.51 | 4.39 | 1.44 |
| | 9-30-54 | 19.60 | 4.40 | 74.6 | 6.96 | 5.19 | .85 |
| | 10-31-54 | 24.25 | 4.65 | 57.5 | 4.19 | 2.41 | 1.93 |
| 3 | 6-15-55 | - 0.60 | - | - | - | - | - |
| | 6-30-55 | 1.20 | 1.80 | 70.4 | 4.12 | 2.90 | 1.24 |
| | 7-31-55 | 7.10 | 5.90 | 84.5 | 8.16 | 6.90 | .86 |
| | 8-31-55 | 17.85 | 10.75 | 81.7 | 9.03 | 7.38 | 1.46 |
| | 9-30-55 | 23.45 | 5.60 | 71.1 | 6.20 | 4.41 | 1.27 |
| | 10-31-55 | 27.10 | 3.65 | 57.8 | 5.98 | 3.46 | 1.05 |
| 5 | 6-15-55 | - 0.60 | - | - | - | - | - |
| | 6-30-55 | 1.05 | 1.65 | 70.4 | 4.12 | 2.90 | 1.14 |
| | 7-31-55 | 6.60 | 5.55 | 84.5 | 8.16 | 6.90 | .80 |
| | 8-31-55 | 18.65 | 12.05 | 81.7 | 9.03 | 7.38 | 1.63 |
| | 9-30-55 | 24.30 | 5.65 | 71.1 | 6.20 | 4.41 | 1.28 |
| | 10-31-55 | 27.65 | 3.35 | 57.8 | 5.98 | 3.46 | .97 |
| 4 | 5-31-56 | 0.30 | - | - | - | - | - |
| | 6-15-56 | 2.15 | 1.85 | 78.3 | 8.74 | 6.84 | .54 |
| | 6-30-56 | 5.65 | 3.50 | 78.3 | 8.74 | 6.84 | 1.02 |
| | 7-31-56 | 14.30 | 8.65 | 80.1 | 8.67 | 6.94 | 1.25 |
| | 8-31-56 | 22.80 | 8.50 | 80.9 | 7.13 | 5.77 | 1.47 |
| | 9-30-56 | 27.65 | 4.85 | 72.7 | 7.63 | 5.55 | .87 |
| 5 | 5-31-56 | 0.30 | - | - | - | - | - |
| | 6-15-56 | 2.30 | 2.00 | 78.3 | 8.74 | 6.84 | .59 |
| | 6-30-56 | 5.65 | 3.35 | 78.3 | 8.74 | 6.84 | .98 |
| | 7-31-56 | 15.55 | 9.90 | 80.1 | 8.67 | 6.94 | 1.43 |
| | 8-31-56 | 23.35 | 9.80 | 80.9 | 7.13 | 5.77 | 1.70 |
| | 9-30-56 | 31.25 | 5.90 | 72.7 | 7.63 | 5.55 | 1.06 |
| 3 | 6-15-57 | - 0.70 | - | - | - | - | - |
| | 6-30-57 | 2.25 | 2.95 | 71.9 | 7.14 | 5.13 | 1.15 |
| | 7-31-57 | 10.05 | 7.80 | 82.9 | 8.47 | 7.02 | 1.11 |
| | 8-31-57 | 18.50 | 8.45 | 80.3 | 7.98 | 6.41 | 1.32 |
| | 9-30-57 | 22.05 | 3.55 | 65.6 | 6.45 | 4.23 | .84 |

Table 9 (concl.)

| Treatment | Date | Accumulated Use Inches | u Inches | $t$ °F | $p_a$ Per cent | $f_a$ | $k_a$ |
|---|---|---|---|---|---|---|---|
| 4 | 6-15-57 | - 0.70 | - | - | - | - | - |
| | 6-30-57 | 2.30 | 3.00 | 71.9 | 7.14 | 5.13 | 1.17 |
| | 7-31-57 | 11.20 | 8.90 | 82.9 | 8.47 | 7.02 | 1.27 |
| | 8-31-57 | 19.50 | 8.30 | 80.3 | 7.98 | 6.41 | 1.29 |
| | 9-30-57 | 24.90 | 5.40 | 65.6 | 6.45 | 4.23 | 1.28 |

Table 10. Statistical analysis of adjusted monthly crop coefficients.

| Months | Years 1954 | 1955 | 1956 | 1957 | Total for Months |
|---|---|---|---|---|---|
| June * | .91 | 1.24 | 1.02 | 1.15 | |
| | .91 | 1.14 | .98 | 1.17 | |
| Sum | 1.82 | 2.38 | 2.00 | 2.32 | 8.52 |
| Mean | .91 | 1.19 | 1.00 | 1.16 | |
| July | .84 | .86 | 1.25 | 1.11 | |
| | .91 | .80 | 1.43 | 1.27 | |
| Sum | 1.75 | 1.66 | 2.68 | 2.38 | 8.47 |
| Mean | .88 | .83 | 1.34 | 1.19 | |
| August | 1.08 | 1.46 | 1.47 | 1.32 | |
| | 1.44 | 1.63 | 1.70 | 1.29 | |
| Sum | 2.52 | 3.09 | 3.17 | 2.61 | 11.39 |
| Mean | 1.26 | 1.55 | 1.59 | 1.31 | |
| September | .89 | 1.27 | .87 | .84 | |
| | .85 | 1.28 | 1.06 | 1.28 | |
| Sum | 1.74 | 2.55 | 1.93 | 2.12 | 8.34 |
| Mean | .87 | 1.28 | .97 | 1.06 | |
| TOTAL FOR YEARS | 7.83 | 9.68 | 9.78 | 9.43 | |

C = 42.1362
Total sum of squares = 44.0276 - 42.1362 = 1.8914
Treatment sum of squares = 43.7665 - 42.1362 = 1.6303
Error sum of squares = 1.8914 - 1.6303 = .2611
Years sum of squares = 42.4481 - 42.1362 = .3119
Months sum of squares = 42.9524 - 42.1362 = .8162
Years x months sum of squares = 1.6303 - .3119 - .8162 = .5022

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square | F |
|---|---|---|---|---|
| Treatment Effects | | | | |
| Years | 3 | .3119 | | |
| Months | 3 | .8162 | | |
| Years x Months | 9 | .5022 | .0558 | 3.21 |
| Error | 16 | .2611 | .0174 | |
| TOTAL | 31 | 1.8914 | | |

* For period June 15 to June 30.

Table 11. Measured and estimated consumptive use - 1954 to 1957.

| Month | Average $k_a$ | Estimated use | Estimated Accumulated use | Measured Accumulated use | Difference | Measured Accumulated use | Difference |
|---|---|---|---|---|---|---|---|
| | | Inches | Inches | Inches | Inches | Inches | Inches |
| 1954 | | | | T-1 | | T-3 | |
| June * | 1.07 | 3.07 | 3.07 | 2.80 | .27 | 2.80 | .27 |
| July | 1.06 | 7.29 | 10.36 | 8.60 | 1.76 | 9.05 | 1.31 |
| August | 1.42 | 6.23 | 16.59 | 13.35 | 3.24 | 15.35 | 1.24 |
| September | 1.04 | 5.40 | 21.99 | 17.95 | 4.04 | 19.75 | 2.24 |
| 1955 | | | | T-3 | | T-5 | |
| June * | 1.07 | 1.55 | 1.55 | 1.80 | .25 | 1.65 | .10 |
| July | 1.06 | 7.31 | 8.86 | 7.70 | 1.16 | 7.20 | 1.66 |
| August | 1.42 | 10.48 | 19.34 | 18.45 | .89 | 19.25 | .09 |
| September | 1.04 | 4.59 | 23.93 | 24.05 | .12 | 24.90 | .97 |
| 1956 | | | | T-4 | | T-5 | |
| June * | 1.07 | 3.66 | 3.66 | 3.50 | .16 | 3.35 | .31 |
| July | 1.06 | 7.36 | 11.02 | 12.15 | .87 | 13.25 | 2.23 |
| August | 1.42 | 8.19 | 19.21 | 20.65 | 1.44 | 23.05 | 3.84 |
| September | 1.04 | 5.77 | 24.98 | 25.50 | .52 | 28.95 | 3.97 |
| 1957 | | | | T-3 | | T-4 | |
| June * | 1.07 | 2.74 | 2.74 | 2.95 | .21 | 3.00 | .26 |
| July | 1.06 | 7.44 | 10.18 | 10.75 | .57 | 11.90 | 1.72 |
| August | 1.42 | 9.10 | 19.28 | 19.20 | .08 | 20.20 | .92 |
| September | 1.04 | 4.40 | 23.68 | 22.75 | .93 | 25.60 | 1.92 |

* For period June 15 to June 30.

Blaney-Criddle formula using adjusted consumptive use factors and crop coefficients is sufficiently accurate for setting up irrigation schedules in north central Kansas.

The average adjusted monthly crop coefficients found in this study were 1.07 for June 15 to June 30, 1.06 for July, 1.42 for August, and 1.04 for September. The largest coefficients were 16 per cent greater for June, 18 per cent greater for July, 20 per cent greater for August, and 15 per cent greater for September than the respective monthly averages. These adjusted crop coefficients can be used in the Blaney-Criddle formula with adjusted consumptive use factors to estimate average monthly consumptive use. To estimate peak monthly consumptive use, the crop coefficients should be increased 15 to 20 per cent.

The adjusted consumptive use factors and crop coefficients estimate monthly consumptive use with less error than the conventional factors and coefficients. Per cent of possible total sunshine hours must be known to evaluate the adjusted consumptive use factor. Few weather stations in Kansas record this information and the records available are of questionable accuracy. Therefore, the use of adjusted consumptive use factors and crop coefficients will be limited.

## ADDITIONAL RESEARCH NEEDED

Additional research is needed in the area of consumptive use by plants to find more accurate methods of estimating water requirements of crops. The results of this study indicate that climatic factors other than mean monthly temperature and sunshine influence consumptive use in Kansas. Studies should be made to determine if the Blaney-Criddle formula can be modified to accurately estimate consumptive use by introducing

additional climatic factors such as humidity and wind speed.

Another promising method of estimating consumptive use from climatological data is by correlating consumptive use with evaporation from an evaporation pan. This will require simultaneous measurement of consumptive use and evaporation along with climatological data at the same location.

## SUMMARY

Consumptive use of corn was measured by soil sampling at the Concordia Irrigation Experiment Field. Monthly consumptive use crop coefficients were calculated for the Blaney-Criddle consumptive use formula. Coefficients were calculated for June, July, August and September. The June coefficient was for the period June 15 to June 30.

The average monthly consumptive use crop coefficients found in this study were 0.73 for June 15 to June 30, 0.87 for July, 1.12 for August and 0.84 for September. The monthly coefficients must be increased 20 per cent for June and September and 40 per cent for July and August to estimate peak monthly use for design purposes.

The Blaney-Criddle formula was adjusted by using per cent of actual sunshine hours per month instead of potential sunshine hours. The consumptive use factors were adjusted and the adjusted monthly crop coefficients were calculated. The adjusted coefficients were 1.07 for June 15 to June 30, 1.06 for July, 1.42 for August and 1.04 for September. The adjusted monthly coefficients must be increased 15 to 20 per cent to estimate peak monthly consumptive use.

Both adjusted and unadjusted monthly crop coefficients were analyzed statistically to see if they had the same relationship to mean

temperature and sunshine hours each year. An analysis of variance was made with a resulting significant F value indicating interaction between months and years. This indicates climatic factors other than mean temperature and sunshine influence consumptive use.

Estimated consumptive use was compared with measured consumptive use. Average monthly crop coefficients and adjusted average monthly crop coefficients were used in the estimates. Results of this study indicate that the Blaney-Criddle formula is not sufficiently accurate to schedule irrigations in north central Kansas.

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Corn consumptive use data - 1954.

| Treatment | Sampling Date | Soil Moisture Inches | Soil Moisture Change Inches | Rainfall Inches | Total Water Use Inches | Accumulated Water Use Inches |
|---|---|---|---|---|---|---|
| 1 | 6-16 | 18.82 | - | - | - | - |
| | 7-29 | 11.66 | - 7.16 | .84 | 8.00 | 8.00 |
| | 8-1 | 16.59 | + 4.93 | - | .54* | 8.54 |
| | 11-6 | 13.29 | - 3.30 | 11.77 | 15.07 | 23.61 |
| 2 | 6-16 | 18.62 | - | - | - | - |
| | 7-22 | 12.70 | - 5.92 | .47 | 6.39 | 6.39 |
| | 7-24 | 16.91 | + 4.27 | .37 | .34* | 6.73 |
| | 11-6 | 11.49 | - 5.42 | 11.77 | 17.19 | 23.92 |
| 3 | 6-16 | 19.00 | - | - | - | - |
| | 7-22 | 12.70 | - 6.30 | .47 | 6.77 | 6.77 |
| | 7-24 | 16.91 | + 4.27 | .37 | .42* | 7.19 |
| | 8-21 | 14.19 | - 2.72 | 3.69 | 6.41 | 13.60 |
| | 8-25 | 18.04 | + 3.85 | 2.46 | .76* | 14.36 |
| | 11-6 | 12.85 | - 5.19 | 5.62 | 10.81 | 25.17 |
| 4 | 6-16 | 18.79 | - | - | - | - |
| | 7-14 | 12.91 | - 5.88 | .39 | 6.27 | 6.27 |
| | 7-18 | 14.70 | + 1.79 | .08 | .64* | 6.91 |
| | 7-30 | 14.01 | - .69 | .37 | 1.06 | 7.97 |
| | 8-3 | 18.63 | + 4.62 | 1.19 | .84* | 8.81 |
| | 9-4 | 14.58 | - 4.05 | 6.52 | 10.57 | 19.38 |
| | 9-10 | 16.20 | + 1.62 | 1.15 | 1.32* | 20.70 |
| | 11-6 | 14.78 | - 1.42 | 2.91 | 4.33 | 25.03 |
| 5 | 6-16 | 18.83 | - | - | - | - |
| | 7-14 | 12.91 | - 5.92 | .39 | 6.31 | 6.31 |
| | 7-18 | 14.70 | + 1.79 | .08 | .56* | 6.87 |
| | 7-25 | 14.72 | + .02 | .37 | .35 | 7.22 |
| | 7-28 | 18.57 | + 3.85 | - | .69* | 7.91 |
| | 8-6 | 16.13 | - 2.44 | 1.19 | 3.63 | 11.54 |
| | 8-9 | 19.08 | + 2.95 | 1.87 | 1.02* | 12.56 |
| | 8-26 | 17.62 | - 1.46 | 3.09 | 4.55 | 17.11 |
| | 8-31 | 17.53 | - .09 | 1.56 | 1.65 | 18.76 |
| | 9-6 | 15.45 | - 2.08 | - | 2.08 | 20.84 |
| | 9-10 | 18.60 | + 3.15 | 1.15 | .92* | 21.76 |
| | 11-6 | 16.05 | - 2.55 | 2.91 | 5.46 | 27.22 |

* Consumptive use estimated during irrigation.

Corn consumptive use data - 1955.

| Treatment | Sampling Date | Soil Moisture Inches | Soil Moisture Change Inches | Rainfall Inches | Total Water Use Inches | Accumulated Water Use Inches |
|---|---|---|---|---|---|---|
| 1 | 6-20 | 15.00 | - | - | - | - |
| | 7-5 | 13.91 | - 1.09 | .49 | 1.58 | 1.58 |
| | 7-28 | 10.36 | - 3.55 | 1.79 | 5.34 | 6.92 |
| | 8-5 | 17.85 | + 7.49 | - | 1.52* | 8.44 |
| | 10-27 | 12.74 | - 5.11 | 6.24 | 11.35 | 19.79 |
| 2 | 6-20 | 14.01 | - | - | - | - |
| | 7-5 | 12.90 | - 1.11 | .49 | 1.60 | 1.60 |
| | 7-21 | 12.05 | - .85 | 1.37 | 2.22 | 3.82 |
| | 7-25 | 13.99 | + 1.94 | .42 | .84* | 4.66 |
| | 8-2 | 11.80 | - 2.19 | - | 2.19 | 6.85 |
| | 8-5 | 13.89 | + 2.09 | - | .78* | 7.63 |
| | 8-25 | 9.80 | - 4.09 | .70 | 4.79 | 12.42 |
| | 8-27 | 13.90 | + 4.10 | - | .36* | 12.78 |
| | 10-27 | 12.99 | - .91 | 5.54 | 6.45 | 19.23 |
| 3 | 6-20 | 13.90 | - | - | - | - |
| | 7-5 | 12.39 | - 1.51 | .49 | 2.00 | 2.00 |
| | 7-26 | 10.53 | - 1.86 | 1.79 | 3.64 | 5.64 |
| | 7-28 | 17.77 | + 7.24 | - | .52* | 6.16 |
| | 8-15 | 12.26 | - 5.51 | .70 | 6.21 | 12.37 |
| | 8-18 | 18.06 | + 5.80 | - | 1.05* | 13.42 |
| | 8-31 | 13.64 | - 4.42 | - | 4.42 | 17.84 |
| | 9-6 | 18.06 | + 4.42 | - | 1.44* | 19.28 |
| | 10-27 | 16.28 | - 1.78 | 5.54 | 7.32 | 26.60 |
| 4 | 6-20 | 14.77 | - | - | - | - |
| | 7-5 | 13.21 | - 1.56 | .49 | 2.05 | 2.05 |
| | 7-21 | 12.33 | - .88 | 1.37 | 2.25 | 4.30 |
| | 7-25 | 15.03 | + 2.70 | .42 | 1.04* | 5.34 |
| | 8-2 | 12.09 | - 2.94 | - | 2.94 | 8.28 |
| | 8-5 | 17.78 | + 5.69 | - | 1.02* | 9.30 |
| | 8-24 | 12.56 | - 5.22 | .70 | 5.92 | 15.22 |
| | 8-26 | 16.53 | + 3.97 | - | .42* | 15.64 |
| | 10-27 | 15.11 | - 1.42 | 5.54 | 6.96 | 22.60 |
| 5 | 6-20 | 14.56 | - | - | - | - |
| | 7-5 | 13.11 | - 1.45 | .49 | 1.94 | 1.94 |
| | 7-13 | 13.92 | + .81 | .89 | .08 | 2.02 |
| | 7-16 | 16.38 | + 2.46 | - | .51* | 2.53 |
| | 7-26 | 14.10 | - 2.28 | .90 | 3.18 | 5.71 |
| | 7-28 | 17.07 | + 2.97 | - | .58* | 6.29 |
| | 8-5 | 14.97 | - 2.10 | - | 2.10 | 8.39 |
| | 8-8 | 18.83 | + 3.86 | .45 | 1.02* | 9.41 |
| | 8-19 | 14.61 | - 4.22 | .25 | 4.47 | 13.88 |
| | 8-22 | 18.67 | + 4.06 | - | 1.23* | 15.11 |
| | 8-31 | 15.07 | - 3.60 | - | 3.60 | 18.71 |

1955 (concl.)

| Treatment | Sampling Date | Soil Moisture Inches | Soil Moisture Change Inches | Rainfall Inches | Total Water Use Inches | Accumulated Water Use Inches |
|---|---|---|---|---|---|---|
| | 9-6 | 18.38 | + 3.31 | - | 1.62* | 20.33 |
| | 10-27 | 17.00 | - 1.38 | 5.54 | 6.92 | 27.25 |
| 6 | 6-20 | 14.78 | - | - | - | - |
| | 7-5 | 13.65 | - 1.13 | .49 | 1.62 | 1.62 |
| | 7-13 | 12.71 | - .94 | .89 | 1.83 | 3.45 |
| | 7-16 | 15.94 | + 3.23 | - | .84* | 4.29 |
| | 8-2 | 11.44 | - 4.50 | .90 | 5.40 | 9.69 |
| | 8-5 | 16.13 | + 4.69 | - | .84* | 10.53 |
| | 8-24 | 12.38 | - 3.75 | .70 | 4.45 | 14.98 |
| | 8-26 | 17.88 | + 5.50 | - | .40* | 15.38 |
| | 10-27 | 13.94 | - 3.94 | 5.54 | 9.48 | 24.86 |

* Consumptive use estimated during irrigation.

Corn consumptive use data - 1956.

| Treatment | Sampling Date | Soil Moisture Inches | Soil Moisture Change Inches | Rainfall Inches | Total Water Use Inches | Accumulated Water Use Inches |
|---|---|---|---|---|---|---|
| 1 | 5-28 | 18.28 | - | - | - | - |
| | 7-30 | 9.96 | - 8.32 | 6.27 | 14.59 | 14.59 |
| | 8-1 | 13.34 | + 3.38 | - | .46* | 15.05 |
| | 10-11 | -- No sample taken -- | | | | |
| 2 | 5-28 | 18.28 | - | - | - | - |
| | 7-30 | 9.96 | - 8.32 | 6.27 | 14.59 | 14.59 |
| | 8-1 | 11.73 | + 1.77 | - | .46* | 15.05 |
| | 8-28 | 8.15 | - 3.58 | 2.37 | 5.95 | 21.00 |
| | 9-1 | 12.26 | + 4.11 | .10 | .60* | 21.60 |
| | 9-22 | 10.49 | - 1.77 | - | 1.77 | 23.37 |
| | 9-25 | 9.39 | - 1.10 | - | 1.10* | 24.47 |
| | 10-11 | -- No sample taken -- | | | | |
| 3 | 5-28 | 18.28 | - | - | - | - |
| | 7-30 | 10.09 | - 8.19 | 6.27 | 14.46 | 14.46 |
| | 8-1 | 13.17 | + 3.08 | - | .44* | 14.90 |
| | 8-28 | 9.76 | - 3.41 | 2.37 | 5.78 | 20.68 |
| | 9-1 | 15.69 | + 5.93 | .10 | 1.00* | 21.68 |
| | 9-22 | 9.58 | - 6.11 | - | 6.11 | 27.79 |
| | 9-25 | 13.21 | + 3.63 | - | .69* | 28.48 |
| | 10-11 | 10.69 | - 2.52 | - | 2.52 | 31.00 |
| 4 | 5-28 | 18.28 | - | - | - | - |
| | 7-30 | 10.69 | - 7.59 | 6.27 | 13.86 | 13.86 |
| | 8-1 | 14.85 | + 4.16 | - | .50* | 14.36 |
| | 8-28 | 9.72 | - 5.13 | 2.37 | 7.50 | 21.86 |
| | 9-1 | 14.91 | + 5.19 | .10 | .96* | 22.82 |
| | 9-22 | 10.88 | - 4.03 | - | 4.03 | 26.85 |
| | 9-25 | 13.07 | + 2.19 | - | .36* | 27.21 |
| | 10-11 | 12.30 | - .77 | - | .77 | 27.98 |
| 5 | 5-28 | 18.28 | - | - | - | - |
| | 7-30 | 9.58 | - 8.70 | 6.27 | 14.97 | 14.97 |
| | 8-1 | 13.71 | + 4.12 | - | .60* | 15.57 |
| | 8-9 | 11.97 | - 1.74 | 1.07 | 2.81 | 18.38 |
| | 8-13 | 15.51 | + 3.54 | .95 | 1.32* | 19.70 |
| | 8-28 | 11.37 | - 4.14 | .35 | 4.49 | 24.19 |
| | 9-1 | 15.00 | + 3.63 | .10 | 1.12* | 25.31 |
| | 9-22 | 9.64 | - 5.36 | - | 5.36 | 30.67 |
| | 9-25 | 13.30 | + 3.66 | - | .42* | 31.09 |
| | 10-11 | 13.08 | - .22 | - | .22 | 31.31 |
| 6 | 5-28 | 18.28 | - | - | - | - |
| | 7-30 | 10.69 | - 7.59 | 6.27 | 13.86 | 13.86 |
| | 8-1 | 14.85 | + 4.16 | - | .44* | 14.30 |
| | 8-28 | 11.61 | - 3.24 | 2.37 | 5.61 | 19.91 |

1956 (concl.)

| Treatment | Sampling Date | Soil Moisture Inches | Soil Moisture Change Inches | Rainfall Inches | Total Water Use Inches | Accumulated Water Use Inches |
|---|---|---|---|---|---|---|
| | 9-1 | 16.36 | + 4.75 | .10 | 1.00* | 20.91 |
| | 9-22 | 10.58 | - 5.78 | - | 5.78 | 26.69 |
| | 9-25 | 13.19 | + 2.61 | - | .84* | 27.53 |
| | 10-11 | --No sample taken -- | | | | |

* Consumptive use estimated during irrigation.

Corn consumptive use data - 1957.

| Treatment | Sampling Date | Soil Moisture Inches | Soil Moisture Change Inches | Rainfall Inches | Total Water Use Inches | Accumulated Water Use Inches |
|---|---|---|---|---|---|---|
| 1 | 6-19 | 16.59 | - | - | - | - |
| | 7-25 | 11.06 | - 5.53 | 2.46 | 7.99 | 7.99 |
| | 7-30 | 14.24 | + 3.18 | - | 1.11* | 9.10 |
| | 9-25 | 9.05 | - 5.19 | 5.11 | 10.30 | 19.40 |
| 2 | 6-19 | 16.59 | - | - | - | - |
| | 7-25 | 10.47 | - 6.12 | 2.46 | 8.58 | 8.58 |
| | 7-30 | 14.72 | + 4.25 | - | 1.33* | 9.91 |
| | 8-19 | 9.85 | - 4.87 | 1.04 | 5.91 | 15.82 |
| | 8-23 | 12.29 | + 2.44 | - | 1.18* | 17.00 |
| | 9-25 | 10.69 | - 1.60 | 4.07 | 5.67 | 22.67 |
| 3 | 6-19 | 16.59 | - | - | - | - |
| | 7-25 | 10.62 | - 5.97 | 2.46 | 8.43 | 8.43 |
| | 7-30 | 15.22 | + 4.60 | - | 1.32* | 9.75 |
| | 8-19 | 10.35 | - 4.87 | 1.04 | 5.91 | 15.66 |
| | 8-23 | 12.61 | + 2.26 | - | 1.18* | 16.84 |
| | 9-25 | 11.91 | - .70 | 4.07 | 4.77 | 21.61 |
| 4 | 6-19 | 16.59 | - | - | - | - |
| | 7-25 | 9.81 | - 6.78 | 2.46 | 9.24 | 9.24 |
| | 7-30 | 14.24 | + 4.43 | - | 1.54* | 10.78 |
| | 8-14 | 9.64 | - 4.60 | .80 | 5.40 | 16.18 |
| | 8-21 | 11.33 | + 1.69 | .24 | 2.21* | 18.39 |
| | 9-3 | 10.70 | - .63 | 1.96 | 2.59 | 20.98 |
| | 9-9 | 12.51 | + 1.81 | - | 1.12* | 22.10 |
| | 9-25 | 12.13 | - .38 | 2.11 | 2.49 | 24.59 |

* Consumptive use estimated during irrigation.

DETERMINATION OF MONTHLY CROP COEFFICIENTS
FOR THE BLANEY-CRIDDLE CONSUMPTIVE USE FORMULA

by

HARRY LEO MANGES

B. S., Kansas State University
of Agriculture and Applied Science, 1949

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An abstract of a thesis

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Water is one of the most important natural resources of Kansas. Dependable water supplies are necessary for industrial growth and expansion of irrigated agriculture. Information on consumptive use of water by farm crops as well as for industrial and domestic purposes is needed. Only when this information is available can the water of Kansas be wisely allocated for maximum benefit to the people.

The Blaney-Criddle consumptive use formula was developed to estimate water requirements for irrigated areas where few or no data, except climatological, were available. The purpose of this study was to determine the monthly consumptive use crop coefficients to use in the Blaney-Criddle formula for corn in Kansas.

Consumptive use of water by corn was measured for the period 1954 through 1957 at the Concordia Irrigation Experiment Field. The monthly consumptive use factors were evaluated from climatological data. The monthly consumptive use crop coefficients were calculated by use of the Blaney-Criddle formula. The average monthly consumptive use crop coefficients found in this study were 0.73 for June 15 to June 30, 0.87 for July, 1.12 for August and 0.84 for September. The largest monthly coefficients were 22 per cent greater for June, 39 per cent greater for July, 38 per cent greater for August and 17 per cent greater for September than the respective monthly averages.

A statistical analysis was conducted to determine if monthly consumptive use is related to mean monthly temperature and sunshine hours in the same way each year. The results indicate weather factors other than mean temperature and sunshine hours influence consumptive use.

Estimated consumptive use was compared to measured consumptive use. Average monthly crop coefficients were used to make these estimates.

Estimated consumptive use varied as much as 6.19 inches from measured consumptive use for the three and one-half month period. This indicates the Blaney-Criddle formula is not sufficiently accurate for scheduling irrigations.

The monthly consumptive use factors for the Blaney-Criddle formula were adjusted to determine if a better relationship between climatic factors and consumptive use could be found. Per cent of possible total sunshine hours was used instead of potential sunshine hours. Adjusted monthly consumptive use crop coefficients were calculated for the same months. The average adjusted monthly crop coefficients were 1.07 for June 15 to June 30, 1.06 for July, 1.42 for August and 1.04 for September. The largest crop coefficients were 15 to 20 per cent greater than the respective monthly average.

A statistical analysis was made and interaction was found between months and years. Estimated consumptive use was compared to measured consumptive use. It was found that the difference was less than using conventional consumptive use factors and crop coefficients but was still too great for irrigation scheduling purposes.